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Impacts of fertigation via surface and subsurface drip irrigation on growth rate, yield and flower quality of *Zinnia elegans*

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ABSTRACT: Drip irrigation combined with split application of fertilizer nitrogen (N) dissolved in the irrigation water (*i.e.* drip fertigation) is commonly considered best management practice for water and nutrient efficiency. This research was conducted to study the influence of drip fertigation in combination with or without N fertilizers on vegetative growth, flowering quality, nutrients concentration in plants and soil fertility after the harvest of zinnia (*Zinnia elegans*). A field experiment was conducted using a randomized complete block split plot design with two systems of drip irrigation (surface and subsurface drip irrigation) and 4 nitrogen rates (0, 30, 60, and 120 kg·ha^{-1}) as the main and split plots, respectively. The results revealed that vegetative growth rate, flowering characteristics , plant chemical contents, plant uptake and available soil from N, P, K, Fe, Mn, and Zn of zinnia increased significantly with increasing N level up to 120 kg·ha^{-1}. A similar trend was also found in the post-harvest soil fertility and nutrient uptake that approved the importance of drip fertigation with N fertilizers. Subsurface drip irrigation system was found to be more efficient than surface drip irrigation system to obtain maximum yield accompanied by the highest nutrients concentration in zinnia plants and soil fertility after harvest.

Key words: available soil nutrients, irrigation system, sandy soil, yield attributes, *Zinnia elegans*.

INTRODUCTION

Field water management practices are the most effective factors affecting crop yield particularly in irrigated agriculture in arid and semi-arid regions. Sandy soils are particularly critical for water management in irrigated agriculture because of their low water-holding capacity and low clay contents. The productivity of these soils is limited by high infiltration rate, high evaporation, low fertility level, low water-holding capacity and low organic matter content (Suganya and Sivasamy 2006). The reasonable use of scarce water resources in Egypt is a top priority for agriculture. The pressure for using water in agriculture sector is increasing to create ways to improve water-use efficiency and take a full advantage of available water. Therefore, the adoption of modern irrigation techniques is needed to increase water-use efficiency. High water application efficiencies are often possible with drip irrigation, since there is reduced surface evaporation, less surface runoff, as well as minimal deep percolation (Jiusheng et al. 2003). Furthermore, a drip irrigation system can easily be used for fertigation, through which crop nutrient requirements can be met accurately. The level of fertigation management for achieving high yields and crop quality appears to exceed what is found with other irrigation methods. There are several other advantages of fertigation through drip irrigation systems, as discussed by Burt et al. (1998).

In recent years, there has been tremendous interest in applying fertilizer nutrients through the irrigation system (fertigation) as a source of providing nutrients to ornamental plants in Egypt. Drip offers the potential of efficient water delivery and complete flexibility with regard to N fertigation.

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Urea is best suited to fertigation because it is relatively cheaper. However, a major concern associated with urea fertigation is soil acidification. Drip irrigation combined with application of N fertilizer dissolved in the irrigation water (*i.e.* drip fertigation) is considered an efficient strategy for water and nutrient application during crop production (Thompson et al. 2000). This is because drip irrigation reduces surface evaporation and deep percolation, obtaining high water use efficiency, while fertigation is wonderfully suitable for regulating the induction, time and level of fertilizer N application, thereby increasing N use efficiency (Darwish et al. 2006). Some of these preference which are illustrate in literature (Asadi et al. 2002; Lesschen et al. 2011; Abalos et al. 2014) through timely nitrogen utilization, excellent uniformity of N function, losses of environmental contamination, movement of tested N into the rooting zone by irrigation water and losses of soil compressed and mechanical deterioration to the plant. Furthermore, Papadopoulos (2000) reported that the fertigation of many plants under suppress irrigation is progressively expanding in several countries of the arid and semi-arid lands. By regulating these N fertilization methods, it is possible to increase the fertilizer N application efficiency and plant productivity and to decrease potential N reduction. This is it may very important in an arid environment region, where N deficiency by volatilization are great (Asadi et al. 2002).

The genus *Zinnia* L. (Asteraceae: Heliantheae) comprises approximately 11 species of annual or perennial herbs or low shrubs. *Zinnia violacea* Cav. (including *Z. elegans* Jacq.) is the most widely cultivated species and is prized among garden ornamental for its large, showy inflorescences and diversity of ray floret colors and petal forms. Zinnia is a popular garden flower because it is extensively used in borders, beds and edges; besides, it is grown as a specialty cut flower and is also a good source of foreign exchange if grown extensively. Zinnia is a summer-season flower in Egypt. Plants are erect, 9 – 100 cm in height, sparsely-branched, with large, ovate to lanceolate leaves. Cultivated forms have one to several whorls of ray florets (Reilly 1978). Good quality and regular supply of flowers can be achieved if proper combinations of N fertilizer with irrigation water are applied to zinnia crop since liquid formulations of various forms of N fertilizers are of current introduction; consequently, studies on fertigation are very limited. There is a need for further studies to decide about the feasibility of using fertigation on a large scale by various farm lands in semi-arid sustems in Egypt. Therefore, the present investigation aimed to examine the effect of drip fertigation in integration with nitrogen fertilizers on the productivity of zinnia plants.

MATERIALS AND METHODS

Field experiments were conducted at the Agricultural Research Station of the Agricultural Research Center, El-Nubaria region, Egypt (longitude: 32°23' E, latitude: 30°58' N; 3 m above sea level) through the 2010 – 2011 growing seasons, where the climate is semi-arid with rare rainfall (20 mm per year). Firstly, soil specimens were possessed by an auger from the soil layers 0 – 30, 30 – 60 and 60 – 90 cm (Table 1) to measure chemical and physical characterizations of the experimental field. The soil texture at this site is mostly sandy through its profile (73.1% coarse sand, 19.6% fine sand, 5.0% silt and 2.3% clay). Soil bulk intensity was measured by cylinders 100 mm in diameter and 60 mm in height in accordance with the classical technique (Grossmann and Reinsch 2002). The water content at the wilting point and field capacity were determined *in vitro* using a pressure plate method (Cassel and Nielsen 1986) at 0.03 and 1.5 MPa, respectively. Three replicates with a randomized complete block split plot design were used in each season. The two used irrigation systems; namely, surface and subsurface drip irrigation, represented the main plot. The 4 nitrogen fertilization rates (0, 30, 60 and 120 kg N·ha^{-1}) as urea (46.6% of N), referred as N0, N30, N60 and N120, respectively, were randomly nested within each main plot of the irrigation system. Nitrogen fertilizer was added in 6 weekly doses starting 30 days after sowing because the application of N in split doses not only enhances absorption by the plants and reduces leaching →

Table 1. Physical and chemical properties of the experimental field soil (averaged over two seasons).

Soil depth (cm)	Soil bulk density (g·cm^{-3})	Field capacity (m^3·m^{-3})	Wilting point (m^3·m^{-3})	Available moisture (m^3·m^{-3})	pH	Organic matter (%)	Texture
0 – 30	1.58	0.072	0.015	0.057	8.00	0.60	Sandy
30 – 60	1.65	0.101	0.017	0.084	7.93	0.49	Sandy
60 – 90	1.60	0.062	0.016	0.046	7.65	0.31	Sandy

and volatilization losses of N, but also becomes available to the plants during initiation of flowers (Iftikhar et al. 2007). Phosphorus fertilizer was applied at a level of 13.5 kg·ha^{-1} of P as calcium superphosphate. All phosphorus was added basally prior planting in all treatments, while the potassium fertilizer was applied after 5 weeks from planting at a value of 41.5 kg·ha^{-1} of K as potassium sulphate by fertigation in 2 equal biweekly amounts. Pests, diseases and weeds control was done at the appropriate time. Hand-harvest was performed about 120 days after sowing. Seeds of zinnia (*Zinnia elegans* Jacq. cv. "Giant Dahlia Flowered Blue Point Series") were sown in plastic pots of 40 cm diameter. Seedlings were transplanted at 2 leaf stages in 3 × 0.9 m plots. Plants row spacing was 45 cm, and the distance between each plant was 30 cm; each row had its own irrigation line positioned near the plants. Plots were separated by border plots. Two seedlings were sown around each dripper to obtain a final plant population of 24 plants plot^{-1}.

Two common irrigation systems were used to irrigate zinnia plants. The first was surface drip irrigation (SDI) and the second was subsurface drip irrigation (SSDI). The drip irrigation lines were twin-wall drip tapes (GR is the common commercial name), with outlets spaced at every 0.5 m, and the drippers used were of a standard (4 L·h^{-1}) discharge at 1.5 bar working pressure. Drip irrigation lines lay above and under rims of plant rows, the composition depth of the subsurface drip lines was 0.25 m with 0.5 m between lateral rows, and the source of irrigation water was groundwater. The specimens of water were collected each irrigation time to analyze the electrical conductivity (EC), main anions (HCO^{3-}, Cl^-, and CO_3^{2-}), and main cations (Mg^{2+}, Ca^{2+}, K^+, and Na^+) and (Chapman and Pratt, 1982), while SO_4^{2-} ions were calculated as the variance between total cations and anions. Means of value of irrigation water analysis are shown in Table 2.

The applied irrigation water amount (*I*) was calculated based on the calculated water requirements for zinnia (mm) using the reference daily evapotranspiraiton (*ETo*; mm.day^{-1}) and the crop coefficient (*Kc*), based on the following equation:

$$I = ETo \times Kc \quad (1)$$

According to Allen et al. (1998), the Penman-Monteith method was used to calculate *ETo*. In this regard, daily meteorological data from a station located away about 500 m from the study site were used. The Food and Agriculture Organization (FAO) Penman-Monteith equation, given by Allen et al. (1998), is:

$$ETo = \frac{0.408\Delta(R_n - G) + \gamma\,(900/(T + 273))\,U_2(e_s - e_a)}{\Delta + \gamma\,(1 + 0.34U_2)} \quad (2)$$

where:

R_n is the net radiation at the crop surface (MJ·m^{-2}·day^{-1}), G is the soil heat flux density (MJ·m^{-2}·day^{-1}), T is the mean daily air temperature at 2 m height (°C), U_2 means the wind speed at 2 m height (m·s^{-1}), e_s is the saturation vapor pressure (kPa), e_a refers to the actual vapor pressure (kPa), $e_s - e_a$ is the saturation vapor pressure deficit (kPa), Δ is the slope of the saturation vapor pressure curve (kPa·°C^{-1}), and γ is the psychrometric constant (kPa·°C^{-1}).

The *Kc* is defined as the ratio between the crop evapotranspiration rate and the reference evapotranspiration rate. Since localized *Kc* values were not available for the study area, the values of *Kc* suggested by FAO-56 (Allen et al. 1998) were used. The *Kc* values of zinnia used (0.36, 1.07, and 1.38, at the initial-, mid-, and late-season stages, respectively) represent the recommended values for a sub-humid climate (minimum relative humidity, *RHmin* ≈ 45%) with a moderate wind speed (U2 ≈ 2 m·s^{-1}). These recommended values must be adjusted in other areas, where the *RHmin* differs from 45% and the wind speed is, sometimes, greater than 2 m·s^{-1} or, occasionally, less than 2 m·s^{-1}. The *Kc* value (larger than 0.45) for the mid-season stage was adjusted using the following equation:

Table 2. Some chemical analyses of the irrigation water. Each value into the table express the mean of irrigation samples (six replicates/value).

EC (dS·m^{-1})	pHw	SAR	Soluble cations and anions (mEq·L^{-1})							
			Cations				Anions			
			Ca^{2+}	Mg^{2+}	Na^+	K^+	CO_3^-	HCO_3^-	Cl^-	SO_4^{2-}
0.45	7.82	2.7	1.0	0.4	2.3	0.2	-	0.1	2.6	1.3

EC = electrical conductivity; SAR = sodium adsorption ratio.

$$Kc = Kc\,(table) + [0.04\,(U_2 - 2) - 0.004\,(RHmin - 45)]\,(h/3)^{0.3} \quad (3)$$

where:

Kc (table) is the *Kc* recommended by FAO-56 (Allen et al. 1998) and *h* is the mean zinnia height during the mid-season stage (m).

After adjustment, the rates of *Kc* values for the 2010 – 2011 growing seasons in the primary, middle and end of season stages were 0.36, 1.07, and 1.38, respectively. The drip irrigation efficacy was assumed to be 0.9, and the root extension coefficient was taken to be 0.8 (Moon and Gulik 1996).

A random specimen of three plants from each plot was taken for recording growth characteristics, viz., plant height per plant, biomass as well as total dry matter (TDM) of shoots, roots and flowers per plant, number of branches and flowers as well as flower diameter per plant. To determine the concentration of nutrients in the leaves and roots, plant tissue analysis was carried out after the leaves and root had been dried in an oven at 70 °C for 48 h and grounded. For the tissues analysis, a 0.25-g sample was digested using wet ash method. The semimicro-Kjeldahl method was used to estimate the total nitrogen content in plants (Bremner and Mulvaney 1982).

Total P was measured colorimetrically using spectrophotometer (Spekol) at 680 nm (Cottenie et al. 1982), whereas total potassium was determined by using Gallen Kamp flame photometer (Cottenie et al. 1982). Also, total micronutrients (Fe-Mn-Zn) concentration was determined in the digestive solution of $HClO_4$, HNO_3 and H_2SO_4, according to Chapman and Pratt (1982), using atomic absorption spectrophotometer (PerkinElmer model 5000). SImilarly, plant samples have been collected baed on the growth stage and stored for analyzing the nutrient uptake pattern. N, P, K, Fe, Mn, and Zn contents in all parts of the plant were analyzed as percentage on dry weight basis and computed to $kg \cdot ha^{-1}$. Similar procedures were approved in the second-season crop also. Reducing sugar, as well as non-reducing sugar percentage, and flower anthocyanins contents ($mg \cdot g^{-1}$) were estimated on a spectrophotometer by using a standard curve (Association of Analytical Communities 1984). However, chlorophyll *a* and *b* in the leaves was determined according to Moran (1982).

On the initial stage and the post-harvest stage, plant samples were taken randomly to study the effect of integrated management on soil fertility and to evaluate the effect of soil characterizations on crop performance in the field. Specimens were taken from the planted soil layer (upper 15 cm), using a single auger and combining 12 samples equally dispersed over the field to 1 composite specimen. The specimens were air-dried, mashed and gritted, and other particles of more than 2 mm were removed with a sieve. For judging completely the characteristics of the soil used, the best methods were applied.

The particle size distribution of the soil was examined following the method described by Dewis and Fertias (1970). Whereas, the Darcy equation was used to measure the hydraulic conductivity according to Singh (1980). Collins Calcimeter was used to calculate the total Ca gasometrically as calcium carbonate following the method described by Dewis and Fertias (1970). Soil reaction (pH) was determined in saturated soil paste (Richards 1954) by combined electrode pH meter. Total soluble salts were determined by calculating the electrical conductivity in the extraction of saturated soil paste in $dS \cdot m^{-1}$ (Jackson 1967). The saturated soil paste extract was used to measure the water soluble cations (Na^+, Ca^{2+}, K^+, and Mg^{2+}) and anions (Cl^-, HCO^{3-}, and CO_3^{2-}) as according to Hesse (1971). In the mean time, the difference between total cations and total anions was considered as the sulphate (SO_4^{2-}) ions concentration. A standardized versenate solution was used to assess the total soluble Mg^{2+} and Ca^{2+} by titration. Titration was, also, used to measure the soluble HCO^{3-} and CO_3^{2-} using standardized H2SO4 solution. Whereas, a the same method using a standardized $AgNO_3$ solution was used to determine soluble Cl^- ions. For determination of soluble cations (Na^+ and K^+ ions), the flame photometer method was used. Soil available N was determined by applying the same method for the total N in the plant. Soil available phosphorus was carried according to Jackson (1967). Available potassium was determined following the method described by Hesse (1971). On the other hand, available iron, zinc and manganese were described by Lindsay and Norvell (1978). The DTPA method (described by Lindsay and Norvell 1978) was used to extract the available Fe^{2+}, Zn^{2+} and Mn^{2+} and then measured using atomic absorption spectrophotometer (PerkinElmer model 5000).

Statistical analyses were carried out using two-factor analysis of variance (ANOVA). Means were separated by Duncan's multiple-range tests by the least significant difference (LSD; $p \leq 0.05$) method using the Costat software (Cohort, Berkeley, CA, USA). All measurements were performed four times for each treatment, and the means were recorded as standard errors (SE).

RESULTS AND DISCUSSION

Data presented in Table 3 show that drip irrigation system (SDI and SSDI) increased growth and yield, and this effect was extremely significant ($p < 0.05$). It is clear that subsurface drip irrigation was related with higher growth and flower quality than surface drip irrigation. Averaged over the two seasons, the subsurface drip irrigation resulted in an increase in plant height, branches number, shoot dry weight, root dry weight, flower diameter, flower number and flowers dry weight by 4.84, 26.43, 16.70, 2.68, 16.48, and 7.15%, respectively, when compared with the surface drip irrigation (Table 3). The capability of subsurface drip irrigation to improve growth and yield could be attributed to the less water lost from soil surface out of vaporization that led to ideal crop yield. Furthermore, subsurface drip irrigation improved the efficiency of water and fertilizers use; this may be attributed to its ability to allow the maintenance of optimum soil moisture content in the root zone (Thompson and Doerge 1996).

Regarding the effect of N fertilizer, it is obvious that N fertilizer additive through fertigation system improved growth and flowering quality, and this effect was greatly significant ($p < 0.05$). At the same time, N fertilizer rate at 120 $kg \cdot ha^{-1}$ produced higher yield than the application rate of 30 or 60 $kg \cdot ha^{-1}$. This is due to the high concentration of nitrogen, which leads to an increase in the number of cells and the cell size of the leaf with an overall increase in leaf production as reported by Hopkins and Hüner (1973). This may be explained by the fact that Nitrogen is an necessary component of amino acids, which →

Table 3. Effect of drip irrigation system, different nitrogen fertilizer rates and their interactive effect on growth parameters (vegetative and flowering) of zinnia plant (mean data for two years).

Treatments		Vegetative growth					Flowering growth	
		Plant height (cm)	Number of branches per plant	Dry weight of shoot (g per shoot)	Dry weight of root (g per root)	Flower diameter (cm)	Number of flowers per plant	Dry weight of flower (g per flower)
Significance level								
DIS		NS	*	*	*	*	*	*
N		*	*	*	*	*	*	*
DIS × N		*	*	*	*	*	*	*
Mean values as affected by irrigation systems								
Surface		51.71 ± 1.43b	4.90 ± 1.29b	89.43 ± 2.93b	16.26 ± 1.42b	6.53 ± 0.23b	12.47 ± 1.45b	5.97 ± 1.08b
Subsurface		54.34 ± 2.14a	6.66 ± 1.91a	97.02 ± 3.72a	19.52 ± 2.13a	6.71 ± 0.31a	14.93 ± 1.24a	6.43 ± 1.19a
Mean values as affected by N fertilizer rate ($kg \cdot ha^{-1}$)								
	N0	49.32 ± 1.01d	4.13 ± 1.06c	84.62 ± 2.67d	12.84 ± 1.92d	4.33 ± 0.52d	9.45 ± 0.96d	5.42 ± 1.51d
	N30	52.53 ± 1.52c	4.93 ± 1.23c	88.91 ± 2.93c	15.92 ± 1.98c	5.47 ± 0.07c	11.37 ± 1.09c	6.52 ± 1.44c
	N60	53.92 ± 1.46b	6.48 ± 1.42b	94.93 ± 4.00b	18.51 ± 3.53b	6.76 ± 0.13b	12.46 ± 1.14b	6.96 ± 1.76b
	N120	56.54 ± 2.14a	7.58 ± 1.51a	104.42 ± 3.67a	22.32 ± 2.54a	6.95 ± 0.12a	14.52 ± 1.22a	7.48 ± 1.62a
SDI	N0	48.54 ± 0.57f	3.57 ± 0.73d	82.45 ± 0.86e	11.25 ± 1.00e	4.27 ± 0.02f	8.42 ± 1.01g	5.32 ± 1.00f
	N30	51.26 ± 1.02e	4.53 ± 1.04cd	86.42 ± 1.16d	14.32 ± 0.98d	5.43 ± 0.06de	10.65 ± 1.19e	6.93 ± 0.42d
	N60	52.71 ± 0.78d	5.41 ± 1.16c	91.43 ± 1.15c	15.43 ± 0.96	5.65 ± 0.13c	11.76 ± 1.01d	6.26 ± 0.98c
	N120	54.67 ± 1.03bc	7.24 ± 0.28bc	97.44 ± 1.04b	20.16 ± 0.61b	6.85 ± 0.14b	12.84 ± 1.15b	7.53 ± 1.59b
SSDI	N0	50.07 ± 0.76e	4.69 ± 1.13cd	86.81 ± 1.72d	14.34 ± 0.86d	5.34 ± 0.05ef	9.53 ± 1.57f	6.40 ± 1.10e
	N30	53.82 ± 0.42cd	5.52 ± 1.32c	91.43 ± 0.96c	17.56 ± 0.99c	6.54 ± 0.11cd	11.62 ± 0.99c	6.94 ± 0.81c
	N60	55.11 ± 0.67b	7.54 ± 0.53ab	98.45 ± 1.14b	21.62 ± 1.11b	6.85 ± 0.12b	13.42 ± 1.04b	7.26 ± 0.53b
	N120	58.42 ± 0.51a	8.91 ± 0.45a	111.37 ± 1.12a	24.54 ± 0.99a	7.03 ± 0.06a	15.67 ± 0.99a	7.92 ± 1.03a

There is no significant difference ($p < 0.05$) between the mean values which have the same letter (Duncan's multiple range test). *Significant ($p < 0.05$); NS = non-significant; DIS = drip irrigation system; N = different nitrogen fertilizer rates; SDI = surface drip irrigation; SSDI = subsurface drip irrigation.

are the building blocks of proteins and nucleic acids, which prepare genetic material and protein (Haque and Jakhro 2001), which are useful in plant growth and also encourage a fast growth. Moreover, Fortun et al. (2006) stated that the improving flowering growth may be attributed to the increase in soil gatherings due to application of nitrogen fertilizer. The composition of these aggregates could protect zinnia plants to be enclosed under soil at all growth stages, and this could improve flower quality. In contrast, our results suggest that fertigation with a urea-based fertilizer seems to be the most suitable option in order to improve flower quality and sustain productivity under specific conditions of these drip irrigation systems, especially, when subsurface drip irrigation system was applied.

The effect of interaction between nitrogen fertilizer application rates and irrigation treatments was significant on the increase in the growth of zinnia plant and flowering quality indicators (Table 2).

Meanwhile, the treatment of application with nitrogen fertilizer at 120 kg·ha^{-1} with subsurface drip irrigation system recorded higher plant height (58.42 cm) and number of branches (8.91), number of flowers (15.67), as well as flower per plant, root dry weight and shoot dry weight (7.92, 24.54, and 111.37 g, respectively). The increase in yield properties in drip fertigation is probably related to improved uptake and availability of nutrients resulting in promoted photosynthesis, leaves extension and translocation of nutrients to reproductive organs compared with conventional nutrients application to soil. These results are in agreement with those obtained by Elhindi et al. (2006), Gengoglan et al. (2006), El-Shawadfy (2008), and Navid et al. (2009).

Table 4. Effect of drip irrigation system, different nitrogen fertilizer rates and their interaction on chemical composition (mean data for two years).

Treatments		Chemical constitutes				
		Chlorophyll a (mg·g^{-1} of FW)	Chlorophyll b (mg·g^{-1} of FW)	Anthocyanins in flowers (mg·g^{-1})	Reducing sugars (%)	Non-reducing sugars (%)
Significance level						
DIS		NS	*	*	*	*
N		*	*	*	*	*
DIS × N		*	*	*	*	*
Mean values affected by irrigation systems						
Surface		0.51 ± 0.13b	0.14 ± 0.02b	243.63 ± 3.00b	1.07 ± 0.21b	10.07 ± 1.31b
Subsurface		0.63 ± 0.16a	0.19 ± 0.03a	253.45 ± 8.14a	1.11 ± 0.02a	11.16 ± 1.81a
Mean values affected by N fertilizer rate (kg·ha^{-1})						
	N0	0.34 ± 0.07c	0.13 ± 0.02d	242.27 ± 2.20d	1.14 ± 0.01c	9.85 ± 0.45b
	N30	0.54 ± 0.11b	0.16 ± 0.02c	256.65 ± 1.96c	1.17 ± 0.01b	10.46 ± 0.54b
	N60	0.62 ± 0.08ab	0.17 ± 0.03b	251.87 ± 4.77b	1.18 ± 0.01b	11.14 ± 0.63a
	N120	0.74 ± 0.06a	0.20 ± 0.03a	257.12 ± 7.90a	1.23 ± 0.03a	12.54 ± 1.15a
SDI	N0	0.31 ± 0.02c	0.11 ± 0.01d	241.52 ± 1.37f	1.15 ± 0.01d	9.58 ± 0.52d
	N30	0.43 ± 0.01bc	0.14 ± 0.01d	245.31 ± 0.78e	1.17 ± 0.01c	10.23 ± 0.33d
	N60	0.53 ± 0.01b	0.15 ± 0.01c	246.65 ± 0.63de	1.18 ± 0.01bc	11.42 ± 0.51c
	N120	0.68 ± 0.02a	0.17 ± 0.01b	249.10 ± 0.72c	1.22 ± 0.01b	12.53 ± 0.53b
SSDI	N0	0.36 ± 0.01c	0.14 ± 0.02d	245.02 ± 0.71e	1.16 ± 0.01cd	10.31 ± 0.65d
	N30	0.66 ± 0.02ab	0.17 ± 0.01cd	248.43 ± 1.23cd	1.18 ± 0.01bc	11.29 ± 0.17cd
	N60	0.70 ± 0.02a	0.21 ± 0.01b	255.12 ± 1.67b	1.21 ± 0.01b	12.52 ± 0.56b
	N120	0.81 ± 0.01a	0.23 ± 0.01a	265.24 ± 1.12a	1.26 ± 0.01a	13.52 ± 1.12a

There is no significant difference ($p < 0.05$) between the mean values which have the same letter (Duncan's multiple range test). *Significant ($p < 0.05$); NS = non-significant; FW = fresh weight; DIS = drip irrigation system; N = different nitrogen fertilizer rates; SDI = surface drip irrigation; SSDI = subsurface drip irrigation.

Relevant data in Table 4 showed the chemical compositions (chlorophylls, flower anthocyanins content and carbohydrates, viz., reducing and non-reducing sugars percentage) of zinnia plants as affected by irrigation systems. SSDI slightly increased the chemical composition in zinnia plant compared with SDI. It was known that the drip irrigation is significant in increasing the nitrogen availability and other nutrients and in increasing their absorption by the plant, increasing total chlorophylls content in leaves. Those came supporting the fact that , under water deficiency stress, the stomata reacts by turning its state to blocked or a half-blocked. and this induce a reduction in uptake CO_2 and subsequently the plants exhaust a huge amount of energy to absorb water, which negatively impact the photosynthetic activities, and then reduce the productivity of plants. These findings indicated that drip irrigation may increase the availability of water in root area, leading to improvements in plant water status and better stomatal conductance (Nunez-Barrious 1991), which eventually reflects on photoassimilate production (Nielsen and Nelson 1998).

Results in Table 4 reveal that the maximum values of chemical compositions were obtained with the highest fertilizer application rate (120 $kg \cdot ha^{-1}$), whereas, the minimum values were obtained by fertigation with the lowest levels of N or without fertilizer application. In this regard, the stimulating effect of nitrogen fertilizer on the increase in the photosynthetic pigments might be due to the promoting effect of the appropriate fertigation, indirectly or directly, on the increase in the absorption and availability of the essential minerals, particularly NH_4^+, Mg^{2+}, and Fe^{2+} cations, which are necessary for the activation of enzyme and formation of chlorophyll and chloroplasts (Stofella and Kahn 2001). Furthermore, Cooper (1974) reported that the N fertilizers commonly cause insufficiency of potassium, enhanced carbohydrate storage and decreased proteins, adjustment in amino acid balance and, then, change in the aspect of proteins; these are a main nutrient in chlorophyll production. Leaf chlorophyll contents were higher with a high dose of nitrogen application (Rathore et al. 1985).Present experiments strongly supports that the nitrogen application indirectly increase the amount of carbohydrates, as a result of enhancing the plants metabolites synthesis which positively affects the productive metabolic activities, and hence raised the carbohydrates content. Higher N application dose showed to be more effective to increase flower quality and yield as well as to reduce the crop duration through early flowering. These treatments encouraged zinnia plants to produce increased photosynthates, which, in sequence, produce higher growth rate, flower good quality, and then early production (Chadaha et al. 1999).

The effect of the interaction between nitrogen fertigation rate and drip irrigation was significant ($p < 0.05$) (Table 4). However, it is clear that the application of N fertilization rate at 120 $kg \cdot ha^{-1}$ with subsurface drip irrigation system was the superior treatment. Similar results to those described were found by Anuradha et al. (1990), Belorkar et al. (1992), and Chadaha et al. (1999).

Regarding the effect of irrigation system, Table 5 shows that irrigation system slightly increased element concentrations in zinnia plants, but it was significantly higher with the subsurface drip irrigation compared to the surface drip. It appears that subsurface drip irrigation creates more appropriate conditions in the root zone area for zinnia plant growth and productions. These results are in agreement with those obtained by Lamm and Trooien (2003), as well as Dukes and Scholberg (2005).

Data revealed that application of N rates had an extremely significant effect on the increase in both micro and macronutrients remained in plants (Table 5). The application rate of 120 $kg \cdot ha^{-1}$ established the highest concentration of nutrients and uptake in plants compared with 30, 60 $kg \cdot ha^{-1}$ and the control treatment. This is because the higher concentration of N, P, and K elements in the leaves of zinnia plants, which is due to the increasing soil moisture content that caused a marked effect on the increase in the solubility of such elements in the soil, promoting the absorbing efficiency of such elements by the plants; it can also form aqueous complexes with micronutrients (Aiken et al. 1985). Moreover, the increase of N fertilizer application rates was linked to the reduction of nutrients leaching that was reflected on the increase in micro and macronutrients concentration in zinnia plants. This indicated a positive effect of the zinnia response to N fertilizer (120 $kg \cdot ha^{-1}$) application by promoting zinnia biomass because of higher N uptake by its roots (Table 5) that showed higher N concentration in the plants. This indicated higher N concentration in the plants. Gaffarzadeh et al. (1998) pointed out that nutrient uptake, particularly nitrogen, increased plant production.

About the effect of combination of nitrogen fertilizer levels and drip irrigation systems, Table 5 revealed that this effect was significant. Nitrogen fertilizer application at 120 $kg \cdot ha^{-1}$ with subsurface drip irrigation system gave the highest values of micro and macronutrients remained in zinnia shoots. The nitrogen uptake was considerably higher under drip →

fertigation at 120 kg·ha^{-1} compared with the other treatments. The P and K uptake values were less or more similar to N uptake. On the other hand, the soil solution phase, which determined mostly by the available soil water, greatly affects the availability and concentration of many nutrients in the soil. The continuous supply of water under drip fertigation system increases the available water in the soil, and results in more available nutrients and the soil, that in turn increases the plant's nutrient uptake. Moreover, the total biomass production in plants was increased as a result of the increase of nutrient uptake resulted from the higher availability of nutrients and water in the soil. This increase in uptake of nutrients may also be referred to the split application of N and K nutrients using the drip fertigation system which minimize the loss in nutrients and make them available to the crop continuously. Tumbare et al. (1999) referred the increase in nutrient uptake to the split application of nutrients using drip fertigation that minimizes the loss in nutrients by leaching and make them available to the plant. The increased yield under fertigation system could be attributed to the increased nutrient uptake, effiiciency of fertilizer using and percentage of nutrient uptake compared to the amount used (Mohammad 2004). In addition, Bharambe et al. (1997) and Veeraputhiran (2000) have reported similar findings regarding the increased uptake of nutrients under drip fertigation systems.

In general, an increase in soil available micro and macronutrients at post-harvest was noticed as compared with initial soil nutrient status. Regarding the effect of drip irrigation systems, subsurface drip irrigation increased soil fertility after

Table 5. Effect of drip irrigation system, different nitrogen fertilizer rates and their interaction on element concentrations in zinnia plants at harvest (mean data for two years).

Treatments		Macronutrients concentration			Micronutrients concentration		
		N (%)	P (%)	K (%)	Fe (mg·kg^{-1})	Mn (mg·kg^{-1})	Zn (mg·kg^{-1})
Significance level							
DIS		NS	*	*	*	*	*
N		*	*	*	*	*	*
DIS × N		*	*	*	*	*	*
Mean values as affected by irrigation systems							
Surface		1.24 ± 0.03	0.21 ± 0.02b	2.19 ± 0.08b	26.05 ± 1.87b	15.07 ± 2.13b	19.45 ± 2.01b
Subsurface		1.25 ± 0.02	0.24 ± 0.02a	2.23 ± 0.21a	28.51 ± 3.25a	16.64 ± 3.02a	22.25 ± 4.53a
Mean values as affected by N fertilizer rate (kg·ha^{-1})							
	N0	1.22 ± 0.01d	0.21 ± 0.02d	2.19 ± 0.21d	24.63 ± 1.25c	12.51 ± 1.04c	18.38 ± 2.06c
	N30	1.24 ± 0.02c	0.23 ± 0.01c	2.16 ± 0.12c	26.15 ± 1.16b	15.52 ± 1.03b	21.00 ± 1.31b
	N60	1.26 ± 0.01b	0.24 ± 0.01b	2.23 ± 0.16b	27.16 ± 1.15b	16.40 ± 1.05b	22.40 ± 1.67b
	N120	1.29 ± 0.01a	0.25 ± 0.02a	2.35 ± 0.17a	30.17 ± 2.83a	19.00 ± 2.18a	26.17 ± 4.41a
SDI	N0	1.21 ± 0.01g	0.20 ± 0.01d	2.08 ± 0.06g	24.00 ± 1.00d	12.00 ± 1.00d	17.65 ± 1.43d
	N30	1.25 ± 0.01e	0.21 ± 0.01c	2.16 ± 0.02e	25.33 ± 0.57cd	15.00 ± 1.00c	19.00 ± 1.00c
	N60	1.26 ± 0.01c	0.22 ± 0.01c	2.24 ± 0.05c	26.33 ± 0.56c	16.00 ± 1.00bc	21.23 ± 1.43c
	N120	1.29 ± 0.01a	0.24 ± 0.01b	2.27 ± 0.03a	28.67 ± 0.57b	17.33 ± 1.15b	22.00 ± 1.00b
SSDI	N0	1.23 ± 0.01f	0.22 ± 0.01c	2.31 ± 0.25f	25.32 ± 1.43cd	13.00 ± 1.00cd	19.00 ± 2.45c
	N30	1.25 ± 0.02d	0.23 ± 0.01bc	2.34 ± 0.11d	27.01 ± 1.00bc	16.00 ± 1.00bc	21.00 ± 1.00bc
	N60	1.26 ± 0.01d	0.24 ± 0.01b	2.63 ± 0.26d	28.00 ± 1.00b	17.00 ± 1.00b	23.65 ± 1.23b
	N120	1.31 ± 0.02b	0.26 ± 0.02a	2.64 ± 0.04b	32.65 ± 1.43a	20.65 ± 1.43a	29.23 ± 1.43a

There is no significant difference ($p < 0.05$) between the mean values which have the same letter (Duncan's multiple range test). *Significant ($p < 0.05$); NS = non-significant; DIS = drip irrigation system; N = different nitrogen fertilizer rates; SDI = surface drip irrigation; SSDI = subsurface drip irrigation.

zinnia plants harvest compared to soil fertility under surface drip irrigation system.

Data in Table 6 showed that the application of N fertilizer with fertigation program had a highly significant effect on the increase in micro and macronutrients remained in soil after zinnia plants harvest. This is mainly attributed to the increase in nitrogen fertilizer rates associated with the decrease of nutrients leaching, which reflected an increasing macronutrients concentration, such as nitrogen in plants, and increasing concentration of these nutrients in soil after plants harvest (Elhindi et al. 2006).

The was a significant ($p < 0.05$) interaction effect between drip irrigation systems and N fertilizer rates (Table 6). The treatments showed significant influence on post-harvest soil available nutrient status, and the highest micro and macronutrients values were noticed under drip fertigation with 120 kg·ha^{-1}. Surface irrigation with soil application of 30 kg·ha^{-1} recorded the lowest values of post-harvest soil available nutrients. The availability and distribution of nutrients in the soil depend on their solubility, moisture and difference. The higher available N, P, K, Fe, Mn, and Zn in the soil after plant harvesting when using drip fertigation system could be attributed to the minimal losses in minerals via leaching and the enhancement of nutrients movement in the soil comparing to surface and/or subsurface drip irrigation system. Slight improvement in the post-harvest soil fertility levels of N, P, K, Fe, Mn, and Zn was noticed in fertigation plots. This confirmed that fertilizers solubilize the unavailable phosphorus to available P form and increase the P use efficiency. Inclusion

Table 6. Effect of drip irrigation system, different nitrogen fertilizer rates and their interaction on post-harvest soil available nutrient status (mean data for two years).

Treatments		Macronutrients concentration			Micronutrients concentration		
		N (mg·kg^{-1})	P (mg·kg^{-1})	K (mg·kg^{-1})	Fe (mg·kg^{-1})	Mn (mg·kg^{-1})	Zn (mg·kg^{-1})
Significance level							
DIS		NS	*	*	NS	*	*
N		*	*	*	*	*	*
DIS × N		*	*	*	*	*	*
Mean values as affected by irrigation systems							
Surface		38.12 ± 2.05b	5.35 ± 1.06b	212.65 ± 11.43b	3.46 ± 0.31	1.16 ± 0.04b	1.11 ± 0.14b
Subsurface		49.27 ± 1.53a	5.85 ± 0.86a	215.57 ± 12.39a	3.65 ± 0.26	1.27 ± 0.07a	1.14 ± 0.15a
Mean values as affected by N fertilizer rate (kg·ha^{-1})							
	N0	39.15 ± 1.20c	5.46 ± 0.31d	201.65 ± 4.52d	3.27 ± 0.21c	1.15 ± 0.02d	0.81 ± 0.05c
	N30	42.35 ± 1.17bc	6.19 ± 0.29c	214.84 ± 12.45c	3.23 ± 0.31c	1.16 ± 0.02c	1.14 ± 0.01b
	N60	47.61 ± 0.57b	6.82 ± 0.25b	233.50 ± 7.55b	3.45 ± 0.11b	1.21 ± 0.02b	1.21 ± 0.06a
	N120	49.35 ± 0.74a	8.13 ± 0.60a	242.50 ± 6.85a	3.82 ± 0.11a	1.31 ± 0.06a	1.23 ± 0.02a
SDI	N0	44.31 ± 0.57f	5.23 ± 0.04g	198.00 ± 2.00f	3.32 ± 0.27d	1.13 ± 0.01g	0.91 ± 0.06d
	N30	46.65 ± 0.52e	6.01 ± 0.38f	205.67 ± 2.42e	3.41 ± 0.45cd	1.14 ± 0.01f	1.13 ± 0.01c
	N60	48.31 ± 0.56d	6.76 ± 0.45e	214.67 ± 2.42d	3.67 ± 0.05c	1.16 ± 0.01e	1.16 ± 0.02c
	N120	51.06 ± 1.10c	7.72 ± 0.26b	224.33 ± 1.43c	3.83 ± 0.02b	1.22 ± 0.02b	1.22 ± 0.02b
SSDI	N0	46.57 ± 1.35e	5.81 ± 0.25e	204.33 ± 1.43e	3.41 ± 0.20cd	1.17 ± 0.01e	0.82 ± 0.03c
	N30	48.63 ± 0.43c	6.68 ± 0.46d	225.00 ± 1.00c	3.42 ± 0.16bc	1.19 ± 0.01d	1.17 ± 0.01bc
	N60	49.67 ± 0.57b	7.06 ± 0.15c	231.31 ± 1.16b	3.72 ± 0.11b	1.21 ± 0.03c	1.25 ± 0.05b
	N120	52.65 ± 0.56a	8.23 ± 0.67a	235.657 ± 2.06a	4.21 ± 0.10a	1.33 ± 0.01a	1.26 ± 0.01a

There is no significant difference ($p < 0.05$) between the mean values which have the same letter (Duncan's multiple range test). *Significant ($p < 0.05$); NS = non-significant; DIS = drip irrigation system; N = different nitrogen fertilizer rates; SDI = surface drip irrigation; SSDI = subsurface drip irrigation.

of fertilizers in the nutrient management program has found to increase the yield of crops by 5 – 10% and the nutrient use efficiency.Supply of water and N fertilizers at shorter intervals increased the nutrients availability in the soil. Moreover, Malik et al. (1994) and Bharambe et al. (1997) have reported that there was increase in the availability of soil nutrients under drip fertigation systems compared to the direct application to the soil.

CONCLUSION

In conclusion, present study indicated that the growth and flowering parameters of zinnia plants was highly enhanced by the application subsurface drip irrigation than it was under surface drip irrigation system. Higher nitrogen application levels not only increased growth rate and production of best-quality flower of zinnia but more enhanced leaf nutrient rates and flower anthocyanin composition. Under semi-arid conditions, drip fertigation with N fertilizers will aid in easy application and concentration of nutrients suitable to the plant according to its developmental stage. It reduced salinization and fluctuation in nutrient values in soil during the plant growing season, promoted higher fertilizer use effectiveness and improved plant productivity.

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